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INVESTIGATIONS ON LIGHT AND HEAT, PUBLISHED WITH APPROPRIATION FROM THE RUMFORD FUND.

XII.

CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF HARVARD UNIVERSITY.

ON THE HEAT PRODUCED IN IRON AND STEEL BY REVERSALS OF MAGNETIZATION.

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Presented May 29th, 1883.

THE following experiments were made with the object of testing certain deductions that seem to follow from Weber's theory of magnetism. The test applies to any theory which regards magnetization to be due to a regular change of position or rotation of the molecules. Weber's theory, doubtless, has strong experimental evidence in its favor, such as the experiments of Beetz,* showing a maximum intensity of magnetization in iron deposited by electrolysis in a magnetic field. But the experiments of Siemens † indicate that the theory must at least be modified; and our experiments upon the heat developed by rapid magnetization and reversals of magnetization seem to show that molecular work — at least of the kind supposed by Weber — does not play so strong a part in magnetic phenomena as has generally been supposed.

Various observers have measured the heat which they supposed to be due to magnetization and to reversals of magnetization. Thus Joule‡ revolved a piece of iron, contained in a tube of water, between the poles of a horseshoe magnet, and measured the rise of temperature and the work done. Van Breda § placed an iron cylinder in a coil of copper wire, bored a hole in the iron, and placed the bulb of a spirit thermometer in this hole. On passing a continuous current of electricity through the coil, no increase of temperature was denoted by the thermometer. When, however, the current was made and broken thirty times a second by an interruptor, the thermometer showed a marked rise in temperature. Grove * surrounded a horseshoe electro-magnet with water at a constant temperature, placed a thermo element upon the armature, which was carefully covered with flannel, and found an increase of temperature upon interrupting or reversing the electrical current. He found no effect in non-magnetic metals. Villari † endeavored to show the same effect from transversal magnetism, by passing an interrupted current through two wires, one of lead, and the other of iron or steel. These wires were bent in the middle, placed in glass cylinders, so that their ends projected through corks at each end of the cylinders. The glass cylinders were filled with absolute alcohol, and were provided with capillary tubes, and thus served as spirit thermometers. The cylinders were placed parallel to each other. The circuit was arranged so that the interrupted current preserved always the same direction in the lead wire, while at each interruption it was reversed through the iron or steel wire. The lead wire showed no increase of heat, while the iron wire exhibited a marked rise of temperature. These various experiments can be explained on the theory that the heating is due to induction currents generated in the mass of the iron by its sudden introduction into a magnetic field. And the effect is greater in the iron and steel than in non-magnetic metals, from the reason that the coefficient of induction is very greatly increased by the substitution of an iron core in an electro-magnet for a non-magnetic core.

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* Pogg. Ann., cxi., 1860.

† Ann. Phys. Chem., 1881.

‡ Phil. Mag., xxiii. 263, 347, 435, 1843.

§ Compt. Rend., xxi. 961; also, Pogg. Ann., lxviii. 552, 1846.

It is claimed by some investigators, however, that the heating is due to a greater degree to the moving or twisting of the molecules of the iron in their beds while under the influence of the alternating and magnetizing currents. Indeed, this view is apparently held by the observers whose experiments we have quoted. And a late paper, by W. Siemens ‡ leads the reader to infer that the internal friction among the molecules of the iron contributes largely to the heating due to reversals of magnetism. The phenomena which support the view that the heat observed when a bar of iron or steel is magnetized and demagnetized is due to molecular action, are the following. The bar gives forth a musical note, which is attributed to longitudinal vibrations of the bar. A bar of steel is lengthened when magnetized. Magnetic filings distributed upon the poles of the electro-magnet move tremu-

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* Phil. Mag., xxxv. 153, 1849; Pogg. Ann., lxxviii. 567.

† Nuovo Cimento, Ser. II., Vol. IV., Nov.-Dec., 1870.

‡ Ann. der Physik und Chemie, No. 12, 1881, pp. 635–656.

lously under the influence of reversals of magnetism, and it is supposed that the particles of the entire mass of the iron partake more or less of this movement. A musical note, however, is given forth by the coil of the electro-magnet before the iron core is inserted, when an alternating current is passed through the coil. This musical note is very weak, and is greatly strengthened by the insertion of the iron core. This note can arise from the attraction of the spires of the coil, which communicate a vibrating motion to the air in the neighborhood of the coil; and this action is much increased by the inductive action caused by the insertion of the iron core.

If we accept Weber's theory, and suppose that the heat developed is due to a movement of the molecules, it follows that, if a piece of iron is alternately magnetized in different directions, the movement of the molecules, and the resultant heat, must be proportional to the angle between the directions of magnetization. Our experiments were made to test this conclusion.

A circular disk of soft iron was placed between the poles of two electro-magnets. A current was passed alternately through the magnets. The rise of temperature of the disk, after a certain time, was measured, when the axes of the poles were in the same straight line, and when they were inclined to each other at an angle a little less than 90°. According to the general theory, the heating should be less in the latter case.

Two disks cut from different pieces of soft iron were used. The diameters were respectively 2.7 cm. and 1.3 cm.; the thickness, 0.1 cm.

In order to make the magnetic field of the same strength in the two positions of the magnets, shunts of suitable resistance were applied to the circuits when the axes of the magnets were in line. The intensity of the field of each magnet was measured, in the two positions, by rotating a coil of fine wire. The arrangement of the shunts was found to answer perfectly; the intensities being unaltered by change of position. In the first series of experiments this precaution was neglected, and there was consequently a greater heating effect in one case than in the other.

The arrangement for reversing the direction of magnetization consisted of a large disk of cherry wood, 91.5 cm. in diameter, and 5 cm. in thickness. Around the circumference of the disk were fastened, at equal distances apart, 104 strips of sheet brass, 1.35 cm. wide. The disk was placed upon one end of an axle, the other end of which carried an iron wheel about 60 cm. in diameter. The iron wheel could be turned by a handle fastened to one of the spokes. All the brass strips were connected by a double copper wire with the axle. Upon the circumference of the wooden disk pressed two brushes of spring brass, arranged at such a distance apart, one above the other, that they were never simultaneously in contact with a brass strip. Each brush consisted of two pieces of brass 2.2 cm. wide. Across the axle was placed a strip of brass, held always in contact with the axle by two wires attached to the table. One of these wires was connected with one pole of the battery. The other pole was connected with the two magnets, and each brush was connected with one of the magnets. It is obvious that, by this arrangement, rotation of the disk would cause the current to pass alternately through each magnet. In the battery circuit was included a tangent galvanometer, to show any alteration in the strength of the current. It was found that the wheel could easily be turned uniformly 100 times a minute. This obviously magnetizes the iron disk 10,400 times a minute in each direction. The molecular arrangement is consequently changed 20,800 times a minute.

The elevation of temperature in the iron disk was measured by means of a thermo-electric element. A wire of German silver was soldered in the middle of one surface of the disk, and in the middle of the opposite surface was soldered an iron wire. The two wires were connected respectively with the wire from a reflecting galvanometer of six ohms resistance, and with the iron wire of another iron and German silver junction. The latter junction was placed in a glass tube, packed with asbestos, and maintained at the temperature of the room. The German silver wire of this junction was connected with the remaining wire of the galvanometer. The larger iron disk was placed perpendicular to the axis of a glass tube, which exactly fitted it; and the two wires from it were passed through corks in the extremities of the tube. The tube was placed perpendicular to the axes of the magnets, with the iron disk horizontal, and in the centre of the field. Several observations were made with the axes of the magnets in line, and with the axes inclined at an angle of about 90°. The wheel was turned for three minutes, in some cases four. At the end of this time the deflection in the galvanometer was 0.5 to 0.8 cm., and in every case the same deflection was obtained after equal times, whether the axes of the magnets were inclined at an angle of 180° or of 90°.

In the preceding experiments the glass tube was pressed against the cores of the magnets; separated from them only by a sheet of paper. It was thought that the heating of the cores by the rapid magnetization and demagnetization might be communicated to the iron disk, and thus mask the heating effect peculiar to it. That the generation of heat in the wire of the magnets had no influence was proved by passing a steady current through the magnets for several minutes, when no deflection was observed in the galvanometer. To avoid the heating effect of the cores, the smaller iron disk was placed in a glass tube which exactly fitted it, as in the preceding case. The ends of the tube were tightly closed, and it was placed in a larger tube, 2.7 cm. in diameter, parallel to the axis. A stream of water was passed through the outer tube. After several attempts, however, it was found that the water pressure was so variable that the arrangement would not answer. The larger tube was then tightly packed with asbestos, a layer of about one centimeter in thickness surrounding the smaller tube. It was thought that this arrangement would certainly prevent any communication of heat during the three minutes that the experiment lasted.

The result of this experiment was the same as before. The deflection due to the heating was unchanged by changing the positions of the magnets. The deflection was about 0.1 cm. smaller than in the preceding cases, probably on account of the smaller size of the disk.

The experiments were then repeated upon a copper disk of about the same size as the larger iron disk. No heating effect whatever was observed. It must be remembered, however, that in this case the thermo-electric element consisted of copper and German silver, the electromotive force of which is much less than that of iron and German silver.

The battery used in these experiments consisted of a modified form of Bunsen cell. The outer vessel contained dilute sulphuric acid; the inner vessel contained a solution of 150 gr. of bichromate of potash and 450 gr. of sulphuric acid to one litre of water. This cell was found to be fully as constant as the Bunsen.

The intensities of the magnetic fields were measured, after the experiments were over, by placing a small coil of copper wire before the poles and reversing the current. The current was somewhat less than when the cells were first set up.

The intensities of the magnets were respectively 2,033 and 760 times the horizontal intensity of the earth's magnetism. In the C. G. S. system the intensities were 343.57 and 128.44.

The results of the preceding experiments show that the chief heating in a mass of iron, that is alternately magnetized in different directions, is not due to molecular motion; at least, if this motion is similar to that assumed by Weber's theory.